BUFFALO NATIONAL RIVER,

ARKANSAS

TEN YEARS OF WATER QUALITY MONITORING

David N. Mott

Resource Management Division

National Park Service - Department of the Interior
Buffalo National River - Harrison, Arkansas

United States Department of the Interior • National Park Service

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May, 1997

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EXECUTIVE SUMMARY

The National Park Service was mandated by congress to preserve the Buffalo River as a free-flowing stream in 1972. The park encompasses 132 miles of the Buffalo River and contains 95,730 acres within its corridor. The river is designated as an Extraordinary National Resource water by the State of Arkansas and is protected by an antidegradation policy.

This report covers ten years of water quality monitoring from 1985 through 1995. The Water Quality Monitoring Program is designed to determine compliance with state standards, define present water quality conditions, characterize patterns and trends, and to elucidate water quality impacts. The report is divided into four sections; Base-flow, Storm-flow, Standards, and Related Studies and Projects.

Fecal coliform bacteria levels remain low in the river with the exception of the Ponca site which shows elevated fecal bacteria caused by cattle operations in Boxley Valley. Bacteria concentrations also appear to be increasing in the river over the last ten years but at a slow rate. High bacteria counts have not been found in association with periods or locations of intensive recreational use. Average bacteria levels are about twice as high in tributaries as in the river. Tomahawk Creek had the highest bacteria counts of any tributary, and Mill, Calf, Richland, Bear, and Clabber Creeks also showed somewhat higher bacteria averages. Mill Creek near Pruitt was the only tributary where the bacteria source was linked to septic systems, the dominant source in the remaining tributaries is agriculture.

Nutrient concentrations appear to increase in the middle section of the river and in middle river tributaries. In the case of nitrates, a strong correlation was demonstrated between an increase in the percent watershed converted to pasture and increased average nitrate concentrations. With more of the Buffalo River Watershed being converted to pasture, it is likely that nutrient concentrations will continue to increase; however, the trend for nitrates over the study period was relatively flat. Six tributaries showed relatively high nitrate concentrations including Davis, Brush, Tomahawk, Calf and both Mill Creeks. Cecil Creek had a high orthophosphate average which will require further investigation. As with bacteria, the dominant source of nutrients is agricultural activities located within tributary watersheds.

In general, turbidity values remain very low during base-flow conditions. Turbidity was highest in the upper river as a result of the sandstone and shale geology in this area of the watershed. Turbidity values are heavily influenced by surface water runoff but may also be influenced by phytoplankton growth in the summer. Beech, Cecil, and Richland Creeks had the highest turbidities, again mostly as a result of the geology in their watersheds.

Specific conductance, temperature, dissolved oxygen, and pH all increased downstream within the river. Specific conductance, dissolved oxygen and temperature also showed distinct fluctuations with the season, while pH did not. Temperature and specific conductance were used to determine the relative influence of springs on each of the tributaries. Base-flow water quality, which characterizes the river about 80 to 85 percent of the time, remains excellent and well below state standards in the Buffalo River and its tributaries.

Storm-flows, or stream conditions characterized by a significant proportion of surface runoff, have been studied on two occasions. The first study examined background sites including a wilderness watershed, while the second study focused on three tributaries with the highest percentage of pasture and agricultural operations in their watersheds. These studies showed a strong correlation between storm-flows and increased bacteria, nutrient, and sediment concentrations. The storm-flow studies also highlighted the problem with current water quality standards because even the wilderness site exceeded state standards for bacteria during storm-flows, while peak bacteria counts from the agricultural tributaries exceeded primary contact standards by 112 times. Phosphate guidelines were also exceeded by as much as seven times during storm-flow conditions in the agricultural tributaries. The Buffalo River is characterized by storm-flow conditions about 15 to 20 percent (65 days) per year. Peak fecal coliform counts in the agricultural tributaries was 45,000 col/100 mL while the maximum count in the river was observed at 13,500 col/100 mL.

Revised and new state standards were proposed based on the water quality monitoring results which more adequately address the Antidegradation Policy applicable to the Buffalo River. The National Park Service will work with the State of Arkansas Department of Pollution Control and Ecology through the administrative procedures of Regulation Eight in an attempt to adopt the new standards. We will also propose resolving issues related to nonpoint source storm runoff and the inability of present standards to address the high magnitude/short duration impacts occurring during storm peaks.

Nine related studies and projects are also discussed to give the reader an idea of the breadth and scope of the ancillary water resources endeavors being conducted in the Buffalo River Watershed. These studies and projects include:

- National Water Quality Assessment (USGS) - Provides verification of BUFFs water quality results, comparisons to other Ozark streams, trace element, pesticide, and hydrocarbon analyses, ecological assessments, and bed sediment and tissue screening.
- Buffalo River Liquid Waste Management System Demonstration Project (ADPCE) - Investigates problems and recommends improvements to confined animal operation permits as required by the conditions of the moratorium.
- Biological Monitoring (UCA, WRD) - Collects aquatic macroinvertebrate community structure and function data and compares to land use and water quality, develops identification keys and sampling methodologies, and integrates biological health with water quality standards.
- Land Use Analysis (AWRC) - Provides land use analysis and trends and compares results to slope, geology, subwatersheds, etc. using a GIS to answer specific management questions.
- Buffalo River Tributaries, Watershed Plan (NRCS) - Allocates $3.1 million toward land treatment, conservation easements, and technical assistance to promote agricultural practices which protect water quality on a cost share basis.

- Ground Water Hydrology Investigation (USGS, OUL) - Characterizes an area of interbasin ground water transfer from the Crooked Creek Watershed to the Buffalo River Watershed and attempts to determine the geologic controls influencing this transfer.
- Geomorphology Investigations (USGS, ADPCE) - Develops understanding of stream habitat and geomorphological responses to land use changes.
- Riparian Restoration/Streambank Stabilization (BUFF) - Uses cedar revetments, cattle exclusion, hayfield setbacks, and vegetative plantings to re-establish native forested buffers along the length of the river.
- Arkansas Water Education Team (NPS, USFS, ADPCE, AG&F) - Three watershed schools are taking part in the W*E*T program which teaches area students water resource values and monitoring techniques and provides water quality data from tributaries.

Recommendations were made based on the findings of this report and ancillary investigations and include; changes in the way the water quality monitoring program is conducted, incorporation of biological monitoring, continued work with other agencies to collect water quality data and implement Best Management Practices, adoption of water quality standards specific to the Buffalo River, and the Development of a Water Resources Management Plan for the National River. Numerous issues also affect the water resources of the Buffalo National River which were beyond the scope of this report to address. Flexibility, good planning, and continued financial and manpower support are required to continue the Water Quality Monitoring Program and provide managers the knowledge to make appropriate and timely decisions regarding water related issues.

Ten Years of Water Quality Monitoring - Buffalo National River

INTRODUCTION

Buffalo National River (BUFF) was established by Congress (P.L. 92-237) in 1972 "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving as a free-flowing stream an important segment of the Buffalo River...". The Buffalo River is also designated by the Arkansas Department of Pollution Control and Ecology (ADPCE) as an Extraordinary Resource Water and a Natural and Scenic Waterway with extraordinary recreation and aesthetic values, the highest ranking of stream quality in the State's hierarchy (ADPCE, 1988). ADPCE applies specific standards to the Buffalo River which exceed those standards applied to waters lacking these designations.

The water quality monitoring program at BUFF is designed to evaluate the waters of the Buffalo River and its major tributaries to determine compliance with state standards. The monitoring also defines the present water quality of the surface and ground waters at BUFF, thereby establishing a baseline against which future changes can be compared. This document is intended, in part, to define the background, or present water quality conditions in a statistically appropriate manner. This information is critical to park managers and state and federal regulatory agencies responsible for making decisions concerning the Buffalo River and the waters within its drainage basin. As the Buffalo River's watershed becomes increasingly populated and developed, background water quality data will be crucial in understanding the effects of changing land use on the riverine environment. The goal of BUFF's water resources program is the protection of park visitors and the preservation of Buffalo River's aquatic resources.

This report presents a comprehensive analysis of the water quality data collected since the inception of the Water Quality Monitoring Program in 1985. Data collected over ten years (1985-1995) have been statistically examined to characterize water quality patterns and trends. The first part of this report concentrates on base-flow data only (base-flow is defined as "generally due to flow of groundwater into the streams when no surface runoff is occurring at the time" (Roberson et. al., 1988)). Any data associated with precipitation induced surface runoff (data collected from the rising or falling limb of storm hydrographs) have been removed. Because of the large amount of data (16,547 entries), average values are the primary statistic referenced for the base-flow section of this report. Data collected as part of BUFF's Water Quality Monitoring Program can be accessed via EPA's STORET database or by contacting the author.

In the second section, storm flow data are examined and reports and investigations relating to storm events are reviewed. In the storm flow section, behavior of parameters through discrete time intervals (sampled storms) and maximum concentrations routinely observed represent the main focus of the discussion. Because nonpoint agricultural sources are the dominant contributors of bacteria and nutrients in the Buffalo River Watershed, it is important to consider storm event data which typically produce the highest concentrations of these parameters.

The third section reviews existing water quality standards for the Buffalo River and presents arguments for the development of new or additional standards. The justification for new standards is based on the results of the water quality data analysis and the tenants of the antidegradation policy as applied to Extraordinary Resource Waters. The final section reviews and discusses ongoing water resource projects as they relate to water quality.

Sampling sites included in the Water Quality Monitoring Program consist of nine river corridor sites, twenty tributaries and three springs (Appendix A). Monitoring station locations were developed in cooperation with hydrologists from the National Park Service's Water Resources Division and researchers from Ouachita Baptist University (Thornton and Nix, 1985). The inset in Appendix A shows the relative drainage basin size for each tributary as a percent of the Buffalo River Watershed.

River sites were selected to be as far below confluencing tributaries as possible to allow for maximum dilution and assimilation. This means water quality could be worse at intervals between sampling sites, especially just below more impacted tributaries. Tributary stations are located as close to their confluence with the Buffalo River as possible. Therefore, water quality could be worse upstream from the sampling sites but still within the park. These factors are described in more detail in the text.

The sampling schedule has not been consistent throughout the reporting period. From 1985 - 1990, the sampling schedule included all river corridor sites year round on a monthly basis and the tributary and spring sites twice each month from May until September. During the first five years, river corridor samples were analyzed for selected metals and nutrient parameters once each season. From 1991 - 1995, samples were collected from both river and tributary sites every other month. Also in 1991, Buffalo National River initiated a cooperative program with the Arkansas Department of Pollution Control and Ecology through which samples collected are analyzed by ADPCE for nutrients, chloride, and sulfate.

SECTION ONE - BASE-FLOW

Fecal Coliform Bacteria - River Corridor

As displayed in Figure 1, Fecal Coliform (FC) concentrations attain their highest average and geometric mean values at station R2, the Ponca sampling site located at the downstream end of Boxley Valley.

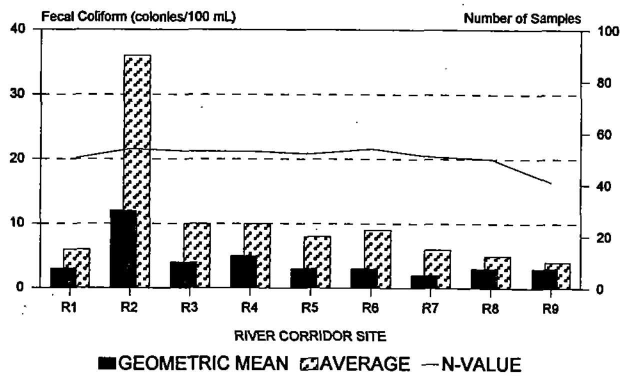

Fig. 1. *Fecal coliform average and geometric mean values at nine Buffalo River sampling stations from 1985-1994.*

The geometric mean concentration is 3.25 times higher at Ponca (13 colonies/100 mL) than the average of all sites (4 col/100 mL). Using a t-test for paired samples, this difference is statistically significant (alpha < 0.05) when compared to both upstream and downstream sampling sites. Masters theses completed by Mott (1990) and Weeks (1992) and other water quality studies (Thornton and Nix, 1985; Fraser, 1988), indicate that cattle operations in Boxley Valley are responsible for the higher bacteria concentrations. Direct access by cattle to tributaries and the river within Boxley Valley is the dominant mode of input during base-flow conditions.

The higher bacteria concentrations at Ponca, while greater than background concentrations, do not represent a significant health threat during base-flow conditions. The state standard for fecal coliform concentrations in primary contact recreation waters is 200 col/100 mL for a geometric mean of five samples collected over a 30 day period. The standard is based on human waste as the source of the bacteria (Cabelli, 1977). The chance of contracting an infectious disease from water born pathogens originating from a human source is much greater than the chance of contacting a disease from an animal source (Burge and Parr, 1980). Therefore, geometric mean concentrations of 13 colonies per 100/mL at Ponca during low flow conditions likely represent a small increase in the possibility of disease transmission.

Figure 2 indicates fecal coliform concentrations have increased over the ten years since the water quality monitoring program started.

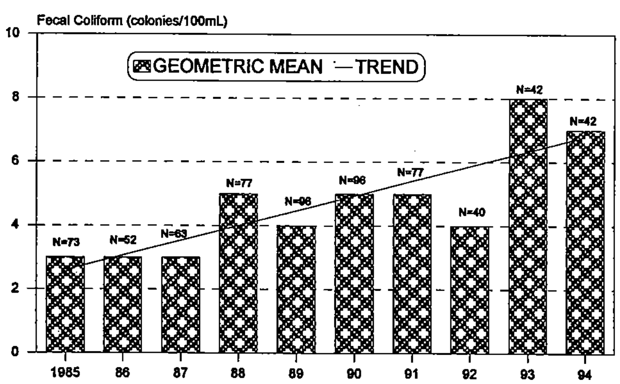

Fig. 2. *Fecal coliform bacteria geometric mean values for the Buffalo River showing computer derived trend line.*

The trend line indicates geometric mean bacteria values were near 2.5 col/100 mL in 1985 for all river corridor sites and near 7 col/100 mL in 1994, an increase of 280 percent. However this increase is not statistically significant as a result of the high degree of scatter among the data points as can be observed in Figure 3 (R = 0.07).

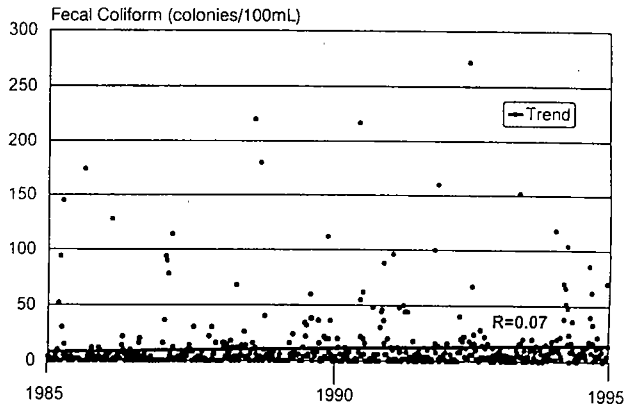

Fig. 3. *Scatter plot of fecal coliform bacteria counts in the Buffalo River during base-flow conditions.*

Given the rate of increase presented in Figure 3, the standard of 200 col/100 mL would not be exceeded under average base-flow conditions for another 428 years.

Increasing trends in bacteria geometric mean values were apparent at all river corridor sites except R4. The fastest rate of increase at any river corridor site for FC is apparent at R2, the Ponca sampling site. Trend analysis indicates fecal coliform counts begin at 8 col/100 mL in 1985 and end at 22 col/100 mL in 1994, an increase of 14 col/100mL over the ten year period. At this rate the standard of 200 col/100 mL would be exceeded at R2 in another 127 years.

Mainly as a result of the higher and increasing fecal coliform concentrations at R2, the National Park Service is actively working with land owners in Boxley Valley to exclude cattle from the Buffalo River within this private use zone of the park. By the end of 1998, the cattle in Boxley Valley should be fenced out of the Buffalo River resulting in protection of water quality and stream banks. Continued monitoring will determine the effectiveness of this action on the bacteria concentrations at Ponca. These steps are needed to comply with the Extraordinary Resource Waters designation which requires no degradation of existing water quality, and to meet NPS mandates to protect and preserve the Buffalo River as a free-flowing stream for present and future generations. The cooperation of Boxley land-owners in this endeavor is to be commended and the example set by their good stewardship may represent a model which can be expanded to other areas of the watershed.

Monthly variations in FC geometric mean values can be seen in Figure 4. Highest bacteria

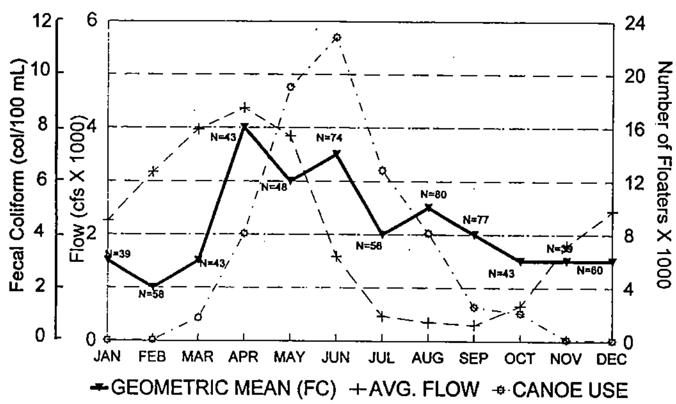

Fig. 4. *Fecal coliform bacteria geometric mean values, average flow, and canoe use by month during 1985-1994.*

concentrations are evident in the spring when storm events flush bacteria from pastures, septic systems, and other sources, into streams and aquifers. Even with the storm flow records removed from the database, the effect of nonpoint source bacteria loading is evident. This figure also displays the overall low concentrations of fecal coliform bacteria during low flow conditions (summer months) when river recreational use is the highest. If human visitation and associated waste products resulted in high bacteria counts in the river, concentrations would be highest during the summer when flows and dilution potential are at a minimum, and recreation use heaviest. In all seasons, bacteria concentrations are well below state standards for primary contact recreation under base-flow conditions.

Fecal Coliform Bacteria - Tributaries

Tributary geometric mean fecal coliform concentrations are shown in Figure 5 for each of the monitored tributary sites. Only Tomahawk Creek (T14, 39 col/100 mL) had a geometric mean exceeding 20 col/100mL, while five tributaries (Mill Creek (T4, 14 col/100 mL, Richland Creek (T9, 14 col/100 mL), Calf Creek (T10, 11 col/100 mL), Bear Creek (T12, 14 col/100 mL), and Clabber Creek (T17, 15 col/100 mL) exceeded 10 col/100 mL. The remaining fourteen tributaries displayed a geometric mean at or below 10 col/100 mL for the ten year period of monitoring.

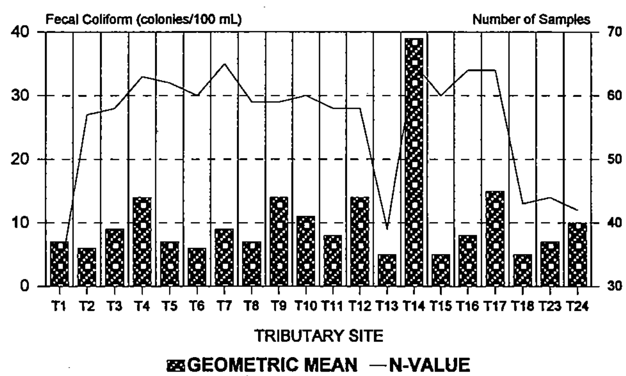

Fig. 5. *Fecal coliform geometric mean values at twenty tributaries from 1985-1994.*

At Tomahawk Creek, higher fecal coliform concentrations routinely observed during base-flow conditions can be attributed to direct deposition of cattle waste as little as 200 feet upstream from the sampling site, in addition to general watershed inputs. The short distance does not allow time for die-off and the relatively small discharge of this creek provides little opportunity for dilution. At Richland Creek, Calf Creek, Bear Creek, and Clabber Creek, the bacterial sources are predominantly from livestock and confined animal operations within their watersheds. During base-flow conditions, direct deposition of cattle waste and ground water inputs account for the majority of the bacteria. Land use studies show these four tributaries have some of highest ratios of land area converted to pasture (Scott, 1995).

Mill Creek (T4) also has livestock operations in its watershed, but a study conducted by Maner and Mott (1991) showed the residential and cabin/camping area near the confluence of Harp Creek causes the greatest rise in bacteria along the length of Mill Creek as shown in Figure 6.

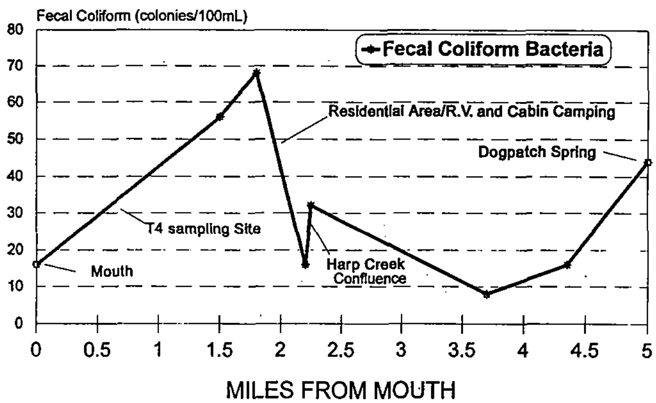

Fig. 6. *Fecal coliform counts at eight sites along Mill Creek (T4).*

Poorly constructed septic systems and septic systems located within the floodplain of Mill Creek are the probable source of most of the fecal bacteria detected at sampling station T4. Fecal coliform/fecal streptococci ratios studied by Fraser (1988) also pointed to human waste as the dominant source of the bacteria in Mill Creek.

Figure 7 shows the geometric mean FC values by year collected for tributary sites and has a computer derived trend line superimposed on the graph.

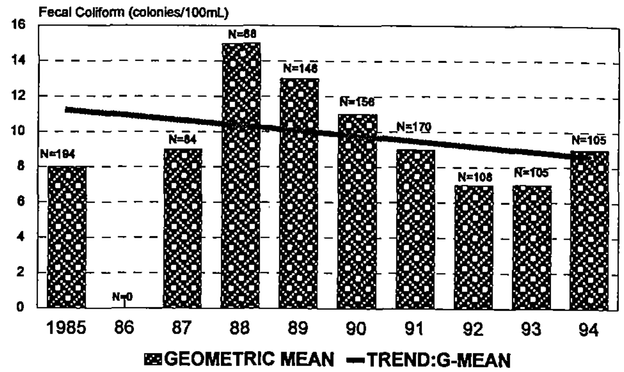

Fig. 7. *Fecal coliform bacteria geometric mean values for twenty tributaries with computer drawn trend line.*

The negative trend line displayed is desirable, however, sampling bias is superimposed over the analysis. Prior to 1991, tributaries were monitored approximately six times each during the summer months. After 1991, samples were collected every-other month throughout the year. Figure 4 shows that FC counts are typically higher from April through September than from October through March. Thus, a negative trend would be anticipated. Allowing for these factors, an examination of the interval from 1991 to 1994 shows a very stable trend indicating that tributary FC concentration are holding relatively constant as a whole.

Given the above discussion, it would also be anticipated that individual tributaries would show negative trends in FC values over the 10 year period of sampling. Trend analysis showed only Mill Creek {T4}, Big Creek {T6}, Calf Creek, Tomahawk Creek, Water Creek, Rush Creek, and Clabber Creek show tendencies towards increasing concentrations of fecal coliform bacteria.

Fecal Coliform Bacteria - Springs

Geometric mean FC values for the three springs sampled were 4 col/100 mL for Luallen Spring, 3 col/100 mL for Mitch Hill Spring, and 11 col/100 mL for Gilbert Spring. Gilbert Spring also shows a positive trend for fecal coliform concentrations over eight years of monitoring. Higher and increasing concentrations of bacteria at Gilbert Spring are most probably related to septic leachate from the town migrating into the spring's karstic recharge area. Gilbert is entirely underlain by limestone and several large sinkholes are visible in the area.

Sources of Fecal Coliform Bacteria

In all areas except Boxley Valley, tributary FC geometric mean values are generally twice as high as those determined for the river corridor, indicating that bacteria loading is occurring from tributaries to the Buffalo River. This is not surprising given the more intensive land use in the surrounding watershed relative to that occurring in or near the river corridor. One of the most common misunderstandings regarding the Buffalo River is that the large number of tourists visiting the river are responsible for pollution. The water quality data and studies collected to date do not support that argument:

1.) If swimmers and canoers were the major source of the bacteria, concentrations would be highest during base-flow in the summer. In reality, highest concentrations are observed during periods of storm runoff, regardless of the season or intensity of visitor use.

2.) Intensive sampling of public use sites conducted in 1985 showed no obvious difference between times when people were swimming and times when swimmers were absent.

3.) The sampling station at Pruitt (R3) is just downstream from one of the busiest summer swimming beaches on the river. Fecal coliform counts are very low at the Pruitt site.

4.) Figure 8 shows a breakdown of bacterial sources from the Middle Tributaries Watershed Project currently being initiated by the Natural Resources Conservation Service (NRCS). The NRCS conducted extensive land use studies in the watersheds of Bear Creek, Brush Creek, Calf Creek, Dry Creek, Richland Creek, and Tomahawk Creek (see Appendix A), and used water quality data and computer modeling to determine the sources of bacteria in this area.

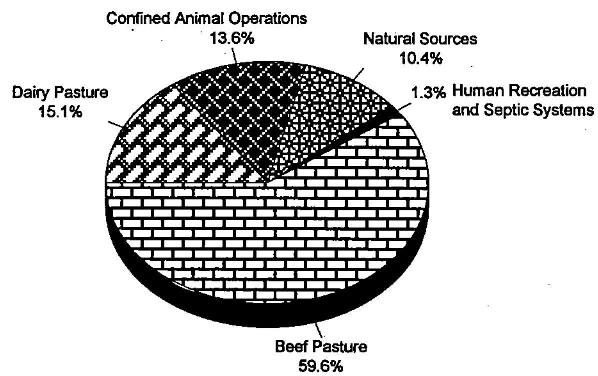

Fig. 8. *Sources of bacteria and their relative contributions in the middle tributaries project watershed area (from NRCS, 1995).*

The NRCS concluded "Approximately 8/10 of one percent of the loading from all sources comes from human recreational activities" (NRCS, 1995). The report also states "Excessive fecal coliform is transported from agricultural systems to the Buffalo River from pasture lands, dairies, swine operations, and direct deposit from cattle wading in streams". This "transport" dominantly occurs in association with storm events and will be treated in more detail in that section.

Nutrients - River Corridor

Nitrogen based nutrient average values for the river corridor sampling sites are shown in Figure 9. Compared to the Wilderness Boundary (R1) background site, nitrate+nitrite-nitrogen values are higher at Ponca (R2), begin to rise again at Hasty(R4), peak at Woolum(R5), and gradually fall until the Mouth (R9) is reached.

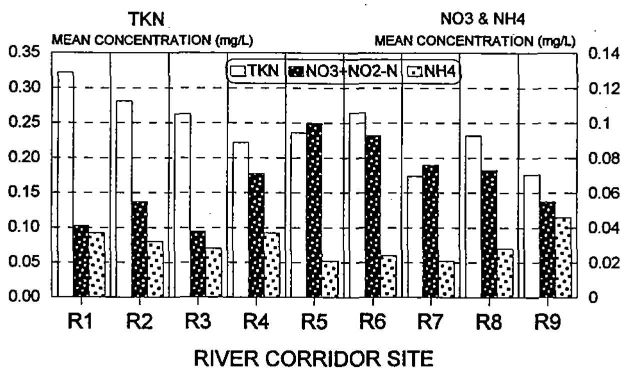

Fig. 9. *Nitrogen based nutrient average values at nine Buffalo River sampling stations from 1985-1994.*

Total Kjeldahl Nitrogen average values should gradually decrease in the downstream direction due to increased dilution, but rise at Woolum, Gilbert, and Rush relative to their neighboring stations. Ammonia average concentrations are relatively high at Hasty and the Mouth. The trend of these nitrogen related parameters tend toward increasing concentrations in the middle portion of the river. This would correlate with land use information which indicates the middle portion of the watershed has the highest percentage of pasture land and other forms of development (Scott, 1995).

With regard to trend plotting, the nutrient parameter most consistently evaluated was nitrate+nitrite-nitrogen. The sampling strategy (methods and times) for this parameter in the river corridor has remained fairly constant over the span of this report. During these ten years,

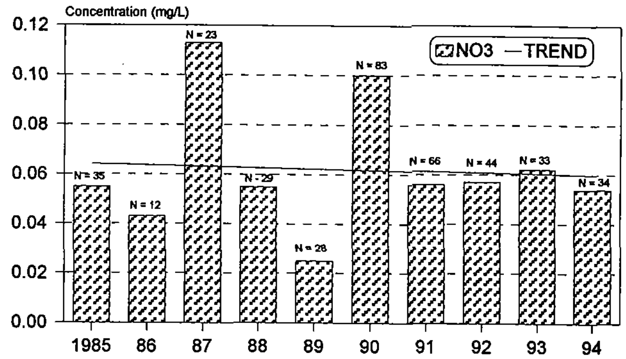

Fig. 10. *Average nitrate+nitrite/nitrogen values in the Buffalo River by year collected with computer drawn trend line added.*

one sample was collected every other month, allowing a fairly unbiased analysis of trend. Figure 10 shows the average values of nitrate+nitrite-nitrogen over the ten year reporting interval. Average values are typically in the 0.06 mg/L range and rarely exceed 0.1 mg/L for any given year. A clear trend in the average values is not apparent and the nitrate concentrations in the river corridor appear to be static during base-flows.

Orthophosphate and total phosphate concentrations are also measured on a routine basis and average 0.010 and 0.015 mg/L, respectively. No definite or apparent trends were observed in phosphate parameters either along the river corridor or through time.

Nutrients - Tributaries

Nitrogen based nutrient average values in the twenty tributaries monitored over the past ten years are shown in Figure 11. Ammonia concentrations averaged 0.032 mg/L for all tributaries and showed little fluctuation. TKN values were typically higher in the upper tributaries (T1 - T11) and lower in the remaining tributaries.

The distribution of TKN averages was not linked to land use trends. Focusing on nitrate+nitrite-nitrogen, five tributaries exceed 0.2 mg/L (Mill Creek {T4}, Davis Creek {T7}, Mill Creek {T11}, Brush Creek{T13}, and Tomahawk Creek {T14}), and Calf Creek (T9) was just under 0.2 mg/L NO2+NO3/N at 0.197 mg/L.

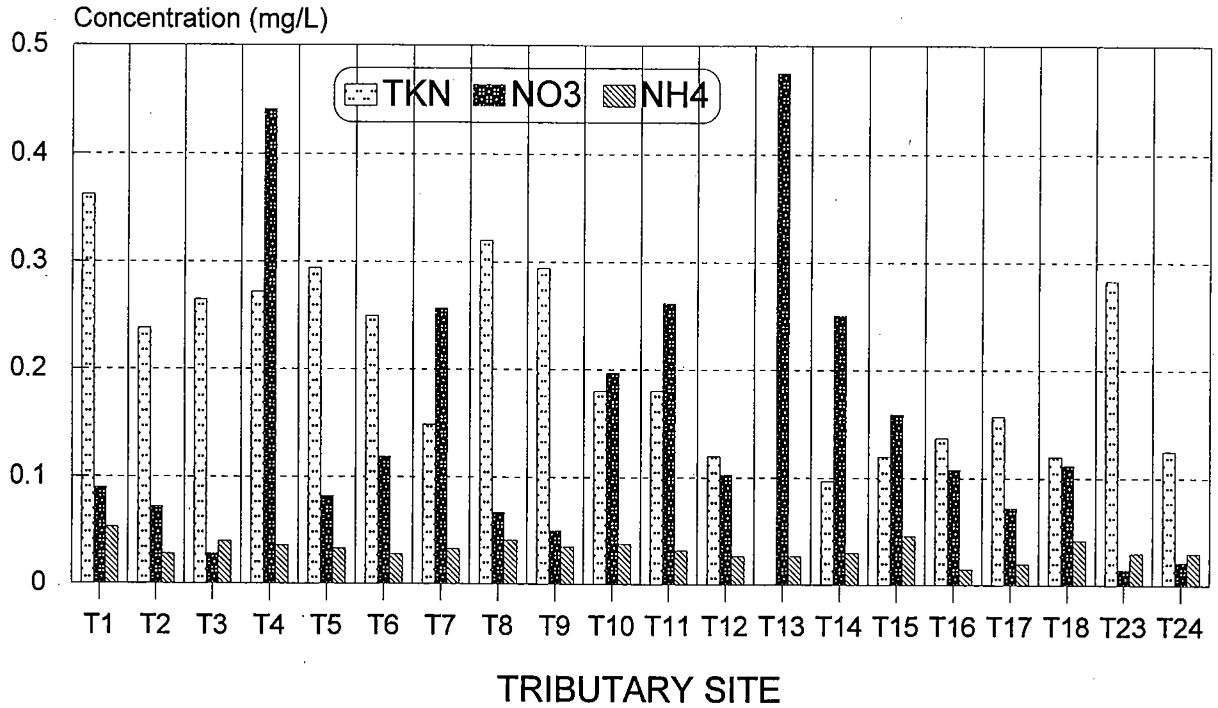

Fig. 11. *Nitrogen based nutrient averages at twenty tributary stations from 1985-1994.*

Nitrate+nitrite-nitrogen loads (average flow times average concentration) in the Buffalo River tributaries are shown in Figure 12 . It is evident from Figure 12 that a significant amount of nitrate is being added to the Buffalo River from Mill Creek (T4), Little Buffalo River (T5), and Big Creek (T6). The contributions from these tributaries are apparently adding to the higher nitrate concentrations observed in the middle section of the Buffalo River.

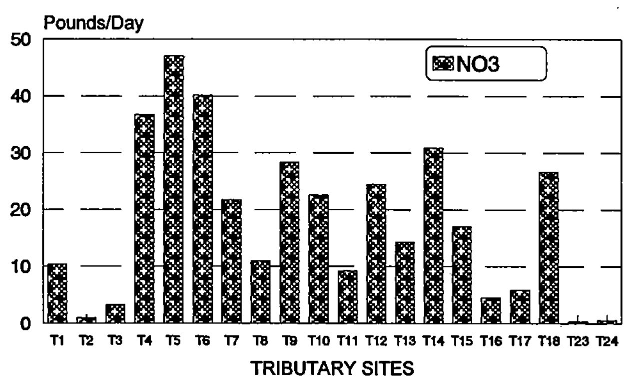

Fig. 12. *Nitrate+nitrite-nitrogen loads in Buffalo River tributaries.*

Mill Creek (T4) was studied intensively by Maner and Mott (1991), and is a spring fed system. Figure 13 was reproduced from this document and shows the highest concentrations of nitrates in Mill Creek are found in the springs at its head. Nitrate values declined from 1.46 mg/L at the Dogpatch springs to 0.35 mg/L at the mouth. Even with the reduction in nitrates it was determined that 96% of the nitrogen load being carried by the Buffalo River below the confluence was supplied by Mill Creek. Maner and Mott hypothesized that the source of the nitrates was from agricultural operations in the spring's recharge area. Given the high ratio of flow versus surface recharge area above the spring, and the karst geology of the area, they also suspected the ground water recharge area extended well beyond the surface watershed of Mill Creek and that interbasin transfer of ground water was contributing nitrates to the springs from many miles away. Two dye tracing studies have been conducted by NPS personnel and have confirmed that interbasin transfer of ground water is occurring between the Crooked Creek Watershed and the Buffalo River Watershed. In both traces, fluorescein dye moved over 2.5 miles in less than five days to emerge from the springs at the head of Mill Creek.

The remaining tributaries with higher nitrate concentrations are also highly spring fed systems, although some tributaries that are highly spring fed are not high in nitrate concentrations. It appears that a combination of a high ratio of spring input combined with a significant portion of the recharge area in agricultural use tends to result in tributaries with higher base-flow nitrate concentrations. Figure 14 shows the relationship between nitrate concentrations and percent watershed converted to pasture for Buffalo River tributaries.

Figure 15 shows that not all watersheds are behaving the same with regard to increased nitrate concentrations per unit area converted to pasture. Between 20 and 40 percent pasture shows the largest amount of scatter between the plotted points. Nitrate concentrations, while

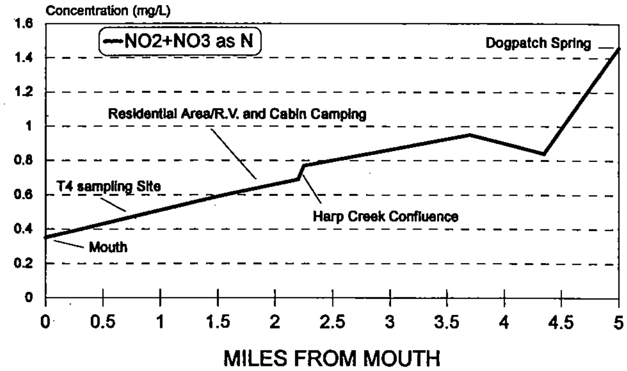

Fig. 13. *Nitrate+nitrite/nitrogen concentrations at eight sites along Mill Creek (T4).*

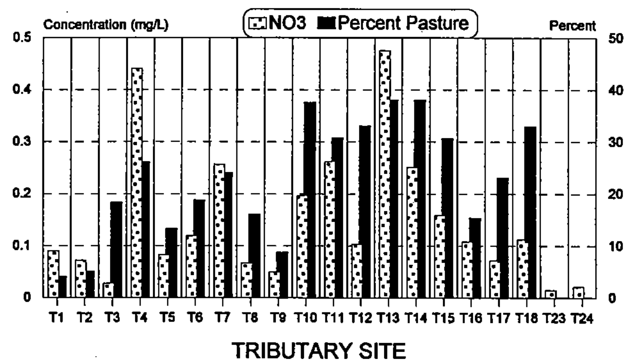

Fig. 14. *Relationship between percent pasture and average nitrate concentrations in Buffalo River tributaries.*

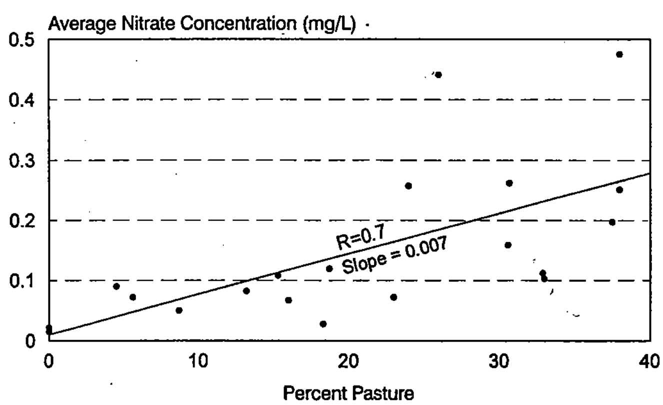

Fig. 15. *Scatter plot and best fit line showing relationship between percent pasture and nitrate average concentrations in Buffalo River tributaries.*

related to percent pasture, are also being influenced by specific pasture management, spatial distribution of pastures relative to the sampling site, and numerous other factors. Cecil Creek (T3), Bear Creek (T12), and Big Creek (T18) are the best examples of tributaries with a relatively large amount of pasture in their watersheds and relatively small average nitrate concentrations. It is unclear at this time what the controlling factors are for the different responses among tributaries to land conversion.

As apparent in Figure 13, nutrient concentrations can be higher near the sources of the nutrients than at the in-park sampling sites. This is further highlighted by the following table which shows average nutrient concentrations at the W*E*T stations (see section 4 for details) are typically higher compared to those found at BUFFs sampling sites further down on the same streams (refer to Appendix A for locations).

	NO3-N (mg/L)	OPO4 (mg/L)	Ammonia (mg/L)
Marshall	0.634	0.083	0.074
T12	0.103	0.006	0.027
St. Joe	0.129	0.027	0.033
T11	0.262	0.007	0.032
Jasper	0.143	0.036	0.065
T5	0.082	0.008	0.033

Orthophosphate average values are shown in Figure 16. The only anomaly is represented by Cecil Creek with concentrations of 0.031 mg/L, which is three times higher than the average for all tributaries combined. The higher concentrations may be related to direct gray water discharges into Cecil Creek from households located upstream from the park, or from people bathing at Cove Springs. Further investigations are needed to help determine the source of the orthophosphate in Cecil Creek.

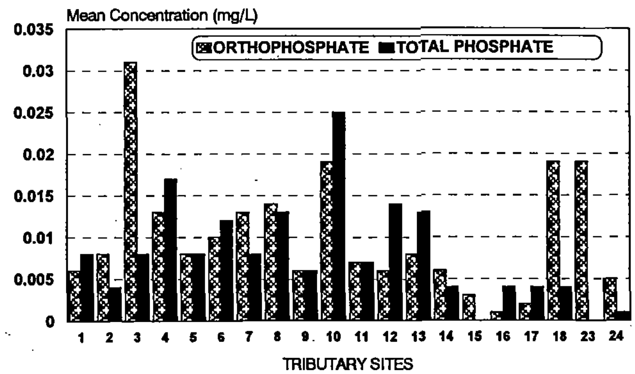

Fig. 16. *Orthophosphate and total phosphate average concentrations in Buffalo River tributaries.*

Figure 16 also shows total phosphate concentrations for the monitored tributaries to the Buffalo River. Interestingly, Cecil Creek has lower total phosphate concentrations than orthophosphate concentrations. This probably results from the fact that total phosphate analyses have not been performed after 1990, whereas, orthophosphate concentrations are still being analyzed bi-monthly.

Nutrients - Springs

The highest average nitrate value recorded at any sampling site came from Gilbert Spring and is 0.791 mg/L. The second highest average value came from Mitch Hill Spring at 0.552 mg/L. Luallen Spring, which has a relatively undeveloped recharge area, had an average nitrate value of only 0.296 mg/l. These values correlate very well with land use in the spring's recharge area. Gilbert Spring is impacted from urban land uses (septic leachate from Gilbert, yard fertilizers, etc.), beef cattle operations, and dairies. Mitch Hill Spring receives nitrate inputs from rural septic systems and beef cattle operations (Aley, 1990).

In addition, Gilbert and Mitch Hill Springs are in very karstic settings, while Luallen Spring's recharge area contains a mixture of strata with a large component of sandstone and shale. Numerous studies conducted in the area (Austin and Steele, 1990; Adamski, 1987; McCalister, 1990; Edwards and Daniel, 1992) indicate karstic aquifers are very susceptible to nitrate leaching into ground water. The data collected for the Buffalo River, its tributaries, and springs supports this hypothesis. In general, the highest nitrate concentrations are observed at springs. The next highest concentrations were in tributaries influenced by springs, then in tributaries with little nearby spring water infusion, and the lowest concentrations are in the river. Superimposed over this pattern are land use factors which tend to distort the general pattern in affected areas.

Total Kjeldahl Nitrogen is more consistent in the three springs ranging from 0.143 at Mitch Hill Spring, 0.181 at Luallen Spring, to 0.213 at Gilbert Spring. Orthophosphate average values ranged from 0.011 at Luallen Spring and Gilbert Spring to 0.018 at Mitch Hill Spring. These values are very similar to averages calculated for the river and its tributaries. Focusing on orthophosphate, it would appear that the consistency of these values in the river, tributary, and springs points to some type of steady state process acting to keep orthophosphate concentrations consistent.

Turbidity - River Corridor

Figure 17 shows the average turbidity values for each river corridor site. Despite the presence of cattle in the Boxley Valley area and the associated trampled and eroding banks, fecal deposition, and poor soil cover in winter, average base-flow turbidity values are less at Ponca (R2) than at the upstream Wilderness Boundary collection site (R1).

The Ponca site has a much greater proportion of limestone (Boone Formation) in its drainage area than the Wilderness Boundary site.

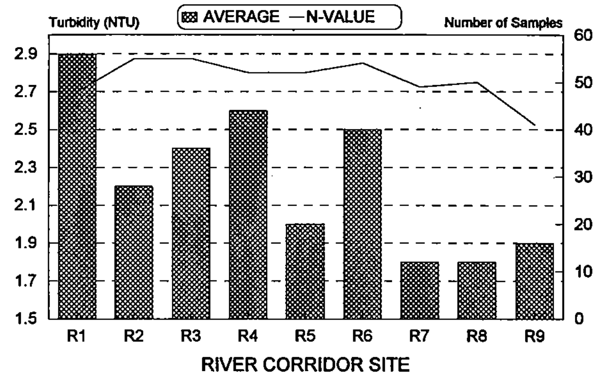

Fig. 17. *Average turbidity values at the nine Buffalo River sampling sites.*

The Boone Formation outcrops in Boxley Valley and its abundant springs and seeps bring clear ground water to the river. The watershed above the wilderness boundary is dominated by interbedded Pennsylvanian aged sandstones and shales which contribute suspended clays.

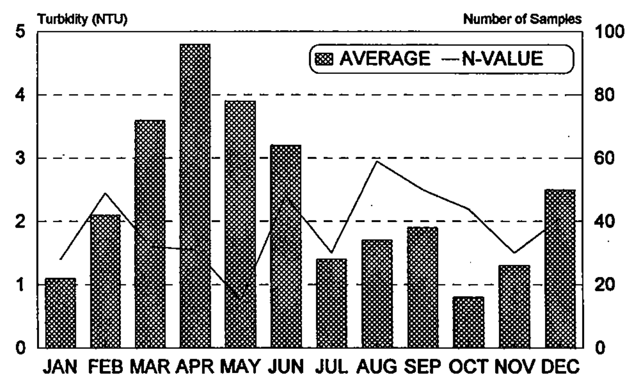

Fig. 18. *Average monthly turbidity values in the Buffalo River.*

Under high flow conditions associated with rain events the opposite was shown (Mott, 1990). Figure 18 shows late winter and spring samples have a significantly higher turbidity than samples collected from the other times of the year. The higher turbidity during these months results from surface runoff and transport of sediment and other particles by high velocity waters. Higher values in the spring have the effect of dampening out the small perturbations that might otherwise be observed between individual stations.

Figure 19 represents an attempt to remove the effects of higher turbidity in the spring and to highlight the relative degree of turbidity at each station caused by algae by focusing only on those samples collected during the summer months. During the summer growth season, the correlation between higher nutrients and higher turbidities is especially pronounced at Hasty (R4). Summer base-flow turbidity is typically related to phytoplankton and algal growth, which in the case of R4 may result from the nutrient loading from Mill Creek and Little Buffalo River which confluence above Hasty.

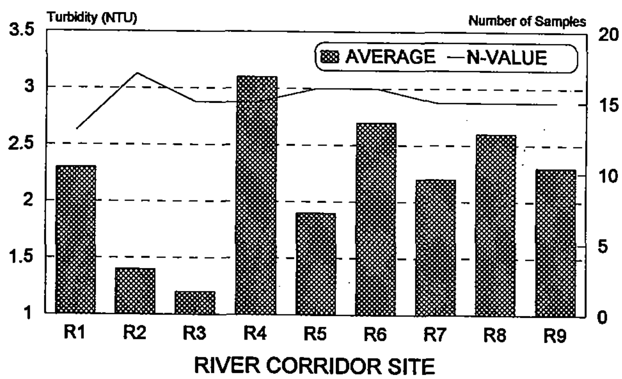

Fig. 19. *Average summer turbidity values at nine Buffalo River sampling sites.*

Generally, the base-flow turbidity of the Buffalo River is between 1 and 3 NTU's (Nephelometric Turbidity Unit). Turbidities as high as 420 NTU's have been recorded in association with rain events. The dominant source of turbidity during high flow times is from erosion of road surfaces and ditches, cattle pastures and other cleared land, and unprotected rapidly eroding cutbanks. Although turbidity and FC concentrations correlate very well during rainstorms (Mott, 1990), a similar relationship is not observed during base-flows, except to say that both are typically low.

Turbidity - Tributaries

The highest average turbidity values shown in Figure 20 come from Beech Creek, Richland Creek, and Cecil Creek. Each of these tributaries drains Boston Mountain sandstones and shales which contribute a higher proportion of suspended load, and thus turbidity, as discussed previously. Indeed, all the tributaries with average turbidities in excess of one NTU have a significant portion of Boston Mountain strata in their watershed, while those under one NTU drain Springfield and Salem Plateau strata.

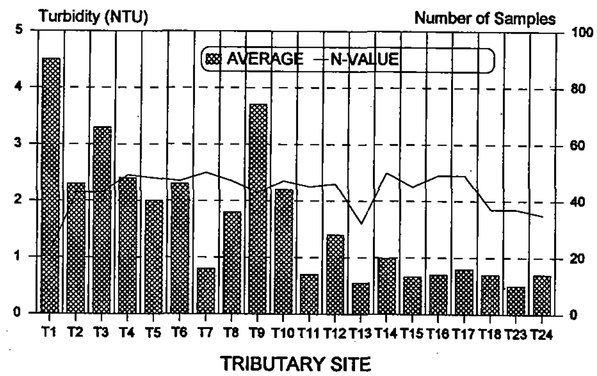

Fig. 20. *Average turbidity values in the tributaries to the Buffalo River.*

Beech Creek has a relatively high turbidity because it is dry most of the summer and samples are therefore not collected during this relatively clearer period (see Figure 18). At Richland Creek, the higher turbidity values resulted in part from samples collected in 1988 during a period of very low-flow. Direct deposition of cattle waste into pools on lower Richland Creek spawned a phytoplankton bloom which increased turbidity by an order of magnitude for a three month duration (summer 1988 average was 11.9 NTU). Cecil Creek's higher turbidity, while related to geology, may also result from the higher phosphate concentrations associated with this stream.

As with the river corridor, the turbidity in the tributaries shows no clear relationship to nutrient concentrations and are probably more a function of geology and sediment transport during rainstorms than from algal growth. For example, Tomahawk Creek (T14) has some of the highest nutrient and fecal coliform concentrations and yet exhibits a very low turbidity. This indicates that a significant amount of ground water recharge feeds Tomahawk Creek, and that this ground water may be contaminated by land use practices occurring in Tomahawk Creek's ground water recharge area.

Turbidity - Springs

Turbidity in springs is a function of the relative amount of discrete recharge associated with the spring's drainage basin, and the rock formations contained within the recharge area. Luallen Spring, which drains Boston Mountain sandstones and shales, had the highest turbidity of 2.5 NTU's, while Gilbert and Mitch Hill Springs, recharged from Springfield Plateau limestones, both showed average turbidities of 0.9 NTU's.

Dissolved Oxygen, Temperature, Conductance and pH - River Corridor

Figure 21 shows average dissolved oxygen concentrations along the river corridor. Sites R1 - R8 are sampled in a synoptic fashion, which means that each site is sampled within a two day period. Site R9 is difficult to access and is sampled when the Lower Buffalo Wilderness tributary samples are collected. Averages are fairly consistent throughout the length of the river, increasing slightly at the mid-river sites (R5 - R7).

Dissolved oxygen and percent saturation are measured on-site with other field parameters. Typically, these measurements are made between 1000 and 1400 hours when photosynthetic activity is relatively high. Figure 22 shows the diurnal behavior of D.O. at a site in the Lower Buffalo Wilderness and demonstrates the relationship between sunlight and the river's dissolved oxygen concentration.

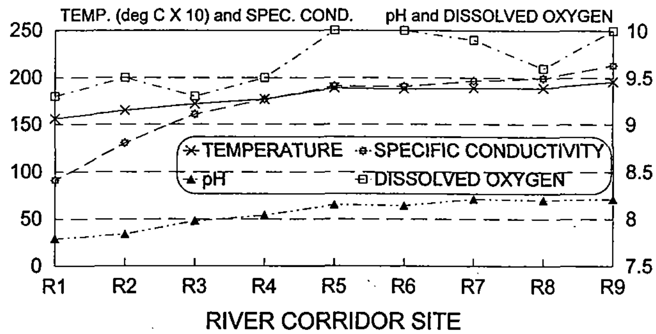

Fig. 21. *Temperature, specific conductance, pH, and dissolved oxygen average values at nine Buffalo River sampling sites.*

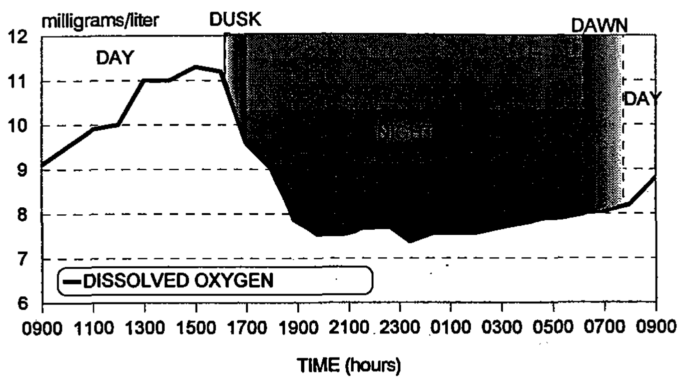

Fig. 22. *Diurnal dissolved oxygen concentrations at a Buffalo River site in the Lower Wilderness on November 1 and 2, 1995.*

Because samples are collected during periods of highest photosynthetic activity, D.O. readings do not reflect potential minimum values which characterize most of the night hours. Rather, D.O. values are often recorded in the super-saturated range, where this super-saturation is extreme, it may reflect excessive photosynthetic activity spawned by nutrient inputs.

Figure 23 shows the monthly fluctuations in D.O. average concentrations. Note the inverse relationship with temperature due to the saturation potential for dissolved oxygen in water. Average dissolved oxygen concentrations range from a low of 7.9 mg/L in July to a high of 12.1 mg/L in January.

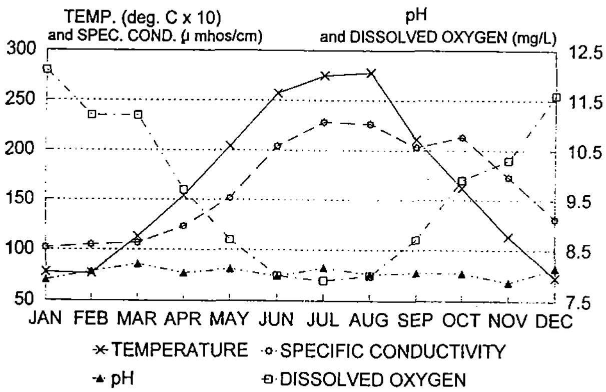

Fig. 23. *Monthly temperature, specific conductance, pH, and dissolved oxygen average values at nine Buffalo River sampling sites.*

Temperature, specific conductance, and pH all tended to increase in the downstream direction along the river as shown in Figure 21. Increased temperatures result from such factors as less shading along wider reaches of the lower river, increased dilution of incoming ground water, friction, and lower elevations.

The observed increases in pH and conductance are closely related and result mainly from increased concentrations of bicarbonates of calcium and magnesium. Addition of bicarbonates increases the concentration of dissolved ions and thus the specific conductance, while these same bicarbonate species also make the solution more alkaline, therefore resulting in a more basic pH.

Monthly variations in these parameters are shown in Figure 23. Temperatures range from an average of between 5 and 10 degrees Celsius in winter to between 25 and 30 degrees Celsius in the summer. It is interesting to note how water temperatures warm relatively slowly in the spring as opposed to how rapidly they cool in the fall, mainly as a result of differences in flow volume.

Increased conductivities in the summer result from increased ratios of ground water to surface water, increased residence times for ground and surface waters, and less dilution of ionic constituents in general. Also, the conductance tends to increase in October, possibly as a result of plant dormancy, and the associated release of ground water. Given the discussion presented regarding pH above, it is interesting to note the lack of a relationship between pH and conductance observed in Figure 23. While conductance varies by over 100 μmhos, average pH values show little variation, remaining around 8.0 ± 0.2.

Dissolved Oxygen, Temperature, Conductance and pH - Tributaries

Dissolved oxygen average values are shown in Figure 24. All tributary D.O. values are biased by the first five years of sampling during which samples were collected from May through September only. Additionally, Beech Creek (T1) and Richland Creek (T9) are intermittent and are often not sampled during the summer low-flow periods. In general, D.O. appears to increase in the middle watershed tributaries. Average temperature values are typically higher than those observed in the river corridor as a result of the sampling bias mentioned previously. Figure 24 also shows that conductance average values are highly variable for each tributary, while pH was again fairly constant increasing slightly in the lower watershed.

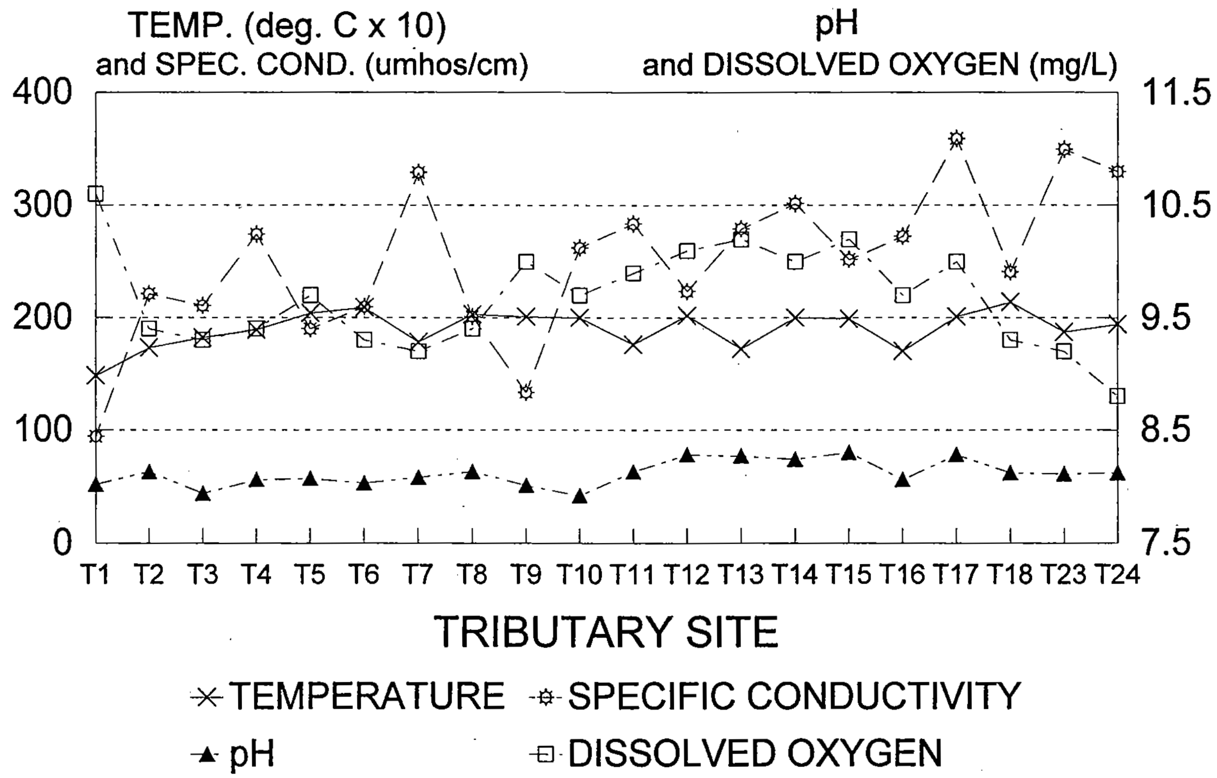

Fig. 24. *Tributary dissolved oxygen, specific conductance, pH, and temperature average values.*

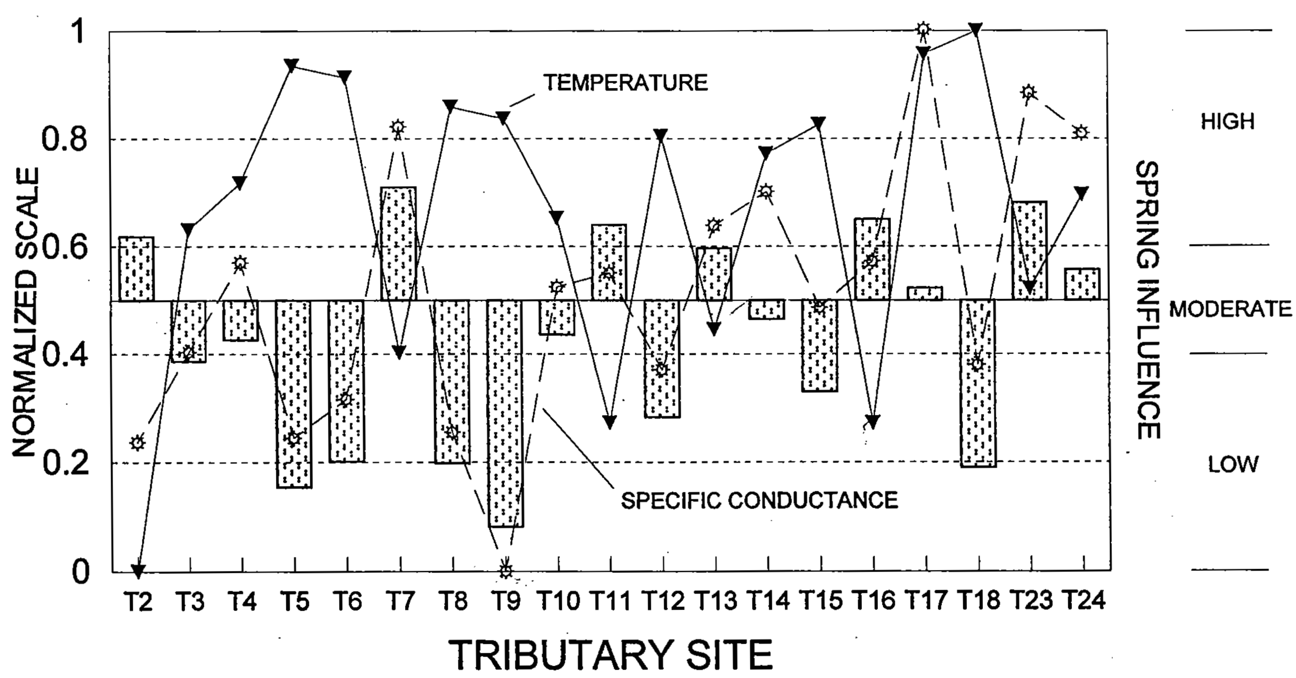

Fig. 25. *Normalized tributary summer average temperatures and conductivities with bars illustrating degree of spring water influence as defined on the right y-axis.*

Temperature and conductance were used in Figure 25 to rank each of the tributaries with regard to their spring water influence. Specifically, average summer temperatures and conductivities were normalized (forced between zero and one with the maximum value set to one and the minimum value set to zero with all other values proportionally distributed between these two values). Low summer temperatures indicate the contribution of relatively cool spring waters near the sampling site. Because conductance is higher in springs than surface water, high conductivities indicate the majority of the water being sampled has been in contact with bedrock for a relatively long period of time. Therefore, high conductance indicates large contributions of ground water, while low temperatures indicate a significant spring is near the sampling station.

Using the above logic, the normalized summer average temperature was subtracted from the normalized average conductance, and the result was plotted as a bar and referenced to the relative scale at right. Tributaries plotting in the "High" category have both high conductance and low temperatures, indicating a high contribution of ground water relatively close to the sampling site. Tributaries in the "Moderate" category have high conductance, but also show higher average summer temperatures, indicating a significant contribution of ground water, with the spring being relatively far from the sampling site. Tributaries in the "Low" category show low summer time conductance and high summer temperatures, indicating relatively low volumes of spring water being contributed to these sites.

Dissolved Oxygen, Temperature, Conductance and pH - Springs

Luallen Spring (S2) and Gilbert Spring (S41) both had higher dissolved oxygen concentrations than Mitch Hill Spring (S33) as displayed in Figure 26. Reasons for this tendency are unclear. Given the low fecal coliform and nutrients found at Mitch Hill Spring, higher biological or chemical oxygen demand would not be expected. Possibly, Mitch Hill Spring is characterized by "full-conduit" delivery, in which atmospheric reaeration is minimized. Mitch Hill Spring also has a high conductance indicating a long residence time for the water in transport to the spring. Gilbert Spring also has a high conductance, but karst windows near the town of Gilbert allow for atmospheric reaeration to occur.

Luallen Spring has the lowest average temperature of 13.6 degrees Celsius. Mitch Hill Spring and Gilbert Spring are slightly higher at 14.9 and 15.1 °C, respectively. Factors controlling spring temperatures include air circulation in associated cave passages, residence time for the recharging ground water, orientation of the spring orifice, and the depth and physiography of the spring's valley. Ideally, spring water temperatures should approach the mean annual temperature for the area, approximately 14.5 °C for northwest Arkansas. Luallen Spring is located in the Boston Mountains and is surrounded by a Beech Maple forest assemblage typically found in more northern latitudes. It would be interesting to plot the latitude at which 13.6 °C is the typical mean annual temperature and determine if Beech Maple forests are common at that latitude.

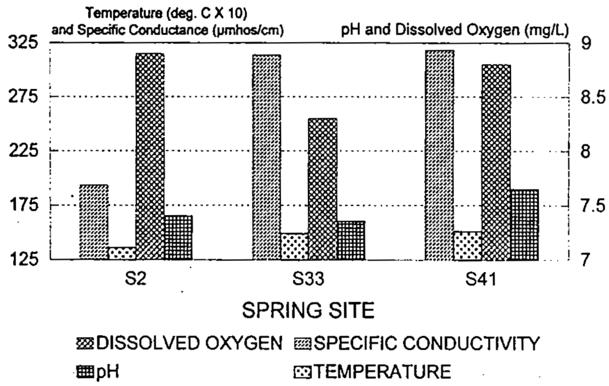

Fig. 26. *Average dissolved oxygen, specific conductance, pH, and temperature values at three springs.*

It is also interesting to note that spring water temperatures, at least in this small subset, increase in the downstream direction as observed with temperatures in the river corridor.

SECTION TWO - STORM FLOW

Two studies have focused on water quality fluctuations induced by storm-runoff. The first study was reported by Mott (1990) and examined the upper Buffalo River at Boxley Valley. Specifically, samples were collected from the Wilderness Boundary Site (R1) and the Ponca Site (R2), during four storms and their associated hydrographs. The second study was conducted in 1994 and 1995, and focused on the tributaries of Calf Creek, Bear Creek, and Tomahawk Creek, which drain into the middle reach of the river (see Appendix A). The data derived from the later study will be published through a cooperative effort with the Arkansas Water Resources Center at the University of Arkansas.

The Boxley study was intended to show the behavior of various parameters from a mainly wilderness watershed, or background site. These data were then compared to water quality below a cattle grazing area located between the Wilderness Boundary Site and the Ponca Site. The more recent tributaries study was conducted to allow further comparisons between watersheds with the knowledge that these three tributaries have some of the most intensive agricultural land use in the Buffalo River basin (Scott and Hofer, 1995; NRCS, 1995).

Storm Flow - Fecal Coliform Bacteria

Figure 27 shows the behavior of fecal coliform in relation to discharge for a storm which occurred on January 25 and 26, 1989. Cumulative rainfall amounts were just over two inches for this storm and the correlation (Spearman's Rank) between discharge and fecal coliform was 0.854 at the Wilderness Boundary and 0.539 at Ponca indicating a relationship between bacteria levels and storm

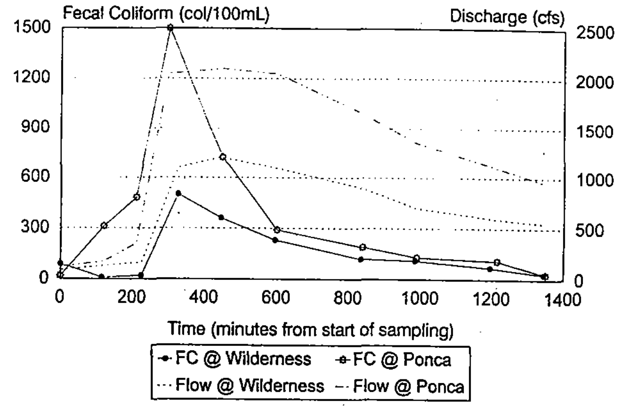

Fig. 27. *Fecal coliform counts and discharge at the Wilderness Boundary and Ponca during a winter storm event.*

flows. Peak bacteria levels were shown to be three times higher, on average, below the cattle grazing area (1500 col/100 mL) as above (500 col/100 mL). It was also noted that fecal coliform counts exceeded state standards for primary contact recreation waters, even when these counts were derived from mainly naturally occurring (wildlife) sources.

The Boxley study highlighted the problem with presently defined water quality standards for fecal coliform bacteria as defined in Regulation #2 (ADPCE, 1995). In summary, the standards were designed mainly to address point source pollution and fail to recognize the rainstorm driven nature of nonpoint source pollution. This argument will be discussed in more detail in section three. The storm event plotted in Figure 27, and the other three storms sampled by Mott (1990) all showed fecal coliform counts higher at Ponca than at the Wilderness Boundary and in excess of state standards for primary contact recreation waters (400 col/100 mL).

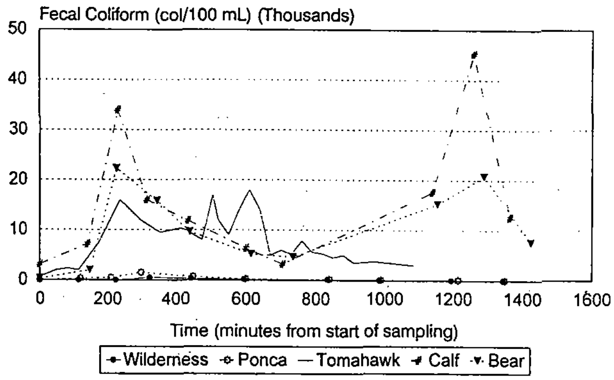

Fig. 28. *Fecal coliform counts and discharge at the Wilderness Boundary and Ponca on the Buffalo River and Tomahawk, Bear, and Calf Creeks during winter storm events.*

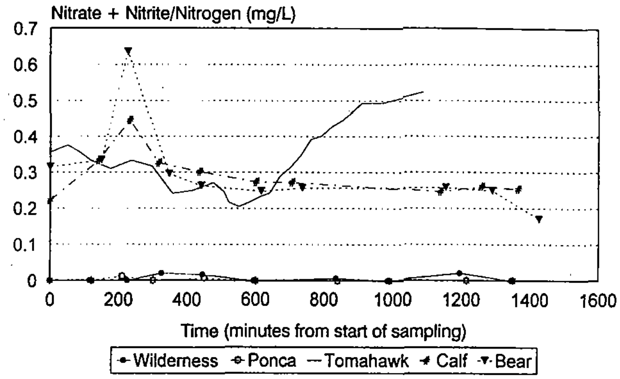

Fig. 29. *Nitrate + nitrite as nitrogen at the Wilderness Boundary and Ponca on the Buffalo River and Tomahawk, Bear, and Calf Creeks during winter storm events.*

Figure 28 shows bacteria counts during storm events can be very high (over 40,000 colonies per 100 mL) in tributaries with significant amounts of agricultural activities in their watersheds. As in the Boxley study, these data were collected from a winter rain event with a total accumulation of just over two inches. Note that the data from the Wilderness Boundary and Ponca sites barely leaves the x-axis when plotted with the tributary rain-event data. Without question, these bacteria counts represent a significant departure from natural, or background, bacteria counts. In fact, bacteria counts in the tributaries routinely displayed peak concentration over 90 times higher than background peaks and 112 times higher than standards for Extraordinary Resource and Natural and Scenic Waterways.

Storm Flow - Nutrients

The behavior of nitrate + nitrite/nitrogen is displayed in Figure 29. As with bacteria counts, nitrate concentrations increased with increasing flow and peaked over 40 times higher in Bear Creek as compared to the background Wilderness Boundary site.

There are no specific water quality standards for nitrates applicable to the surface waters of the State of Arkansas. Guidelines are presented in Regulation #2 for total phosphate concentrations which indicate they should not exceed 0.1 mg/L in streams. Figure 30 shows total phosphate concentrations remained below this threshold at the Wilderness Boundary and Ponca sites during rain events, but exceeded 0.1 mg/L by approximately seven times in Calf and Bear Creeks.

Turbidity and total suspended solids were also significantly higher during rain events at the tributary sites as compared to the background, Wilderness Boundary, site. This indicates increased erosion rates in these watersheds and excessive loading of sediments to the Buffalo River from these tributaries. Detailed loading calculations and comparisons will be presented in the report presently being drafted at the Arkansas Water Resources Center.

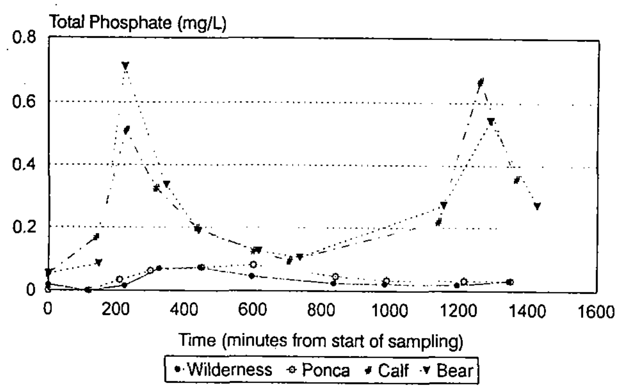

Fig. 30. *Total phosphate concentrations at the Wilderness Boundary and Ponca on the Buffalo River and Calf and Bear Creeks during a winter rain event.*

Storm Flow - Discussion

Higher storm flow concentrations are a concern in three ways. First, higher bacteria counts, nutrient concentrations, and sediment loads are impacting the quality of the Buffalo River's water and degrading the uses for which the National River was established. An analysis of peak flow occurrence from daily discharge plots for the years 1994 and 1995 indicate the Buffalo River is influenced by storm water runoff about 15 to 20 percent of the time, or about 65 days per year. The maximum fecal coliform count observed in the Buffalo River during routine water quality monitoring was 13,500 col/100 mL at Gilbert. Limited storm event monitoring at the Highway 65 bridge showed a peak fecal coliform count of 10,000 col/100 mL. This means visitors to the Buffalo River could be facing bacteria counts exceeding standards and background conditions many times through the course of a year.

Secondly, nonpoint pollution loads appear to be impacting the aquatic life in streams receiving detectable increases of bacteria and nutrients. Studies by Mathis (1991 and 1992) and ongoing research indicate macroinvertebrate populations are skewed toward more pollution tolerant organisms in streams with degraded storm water chemistry. Ongoing studies are also looking at fish communities to determine if changes are occurring in these populations as well.

Third, investigations by Steele et. al. (1990) and McCalister (1990) showed increased concentrations of nitrates in ground water below areas with a significant percentage of agricultural operations as compared to forested areas. Because ground water is the predominant source of flow to the Buffalo River and its tributaries 80 to 85 percent of the year, increased nutrient concentrations in ground water could provide a continuous source of excess nutrients during base flow conditions.

Additionally, organic forms of nitrogen and phosphorus are loaded into the Buffalo River during storm runoff events as pastures, confined animal operation, and other sources are flushed. Reports (Bigger and Corey, 1968; and Hynes, 1972) have stated organic nutrients can be assimilated in river bottom sediments, subsequently converted by microorganisms into soluble forms, and released to the water column continuously during base-flow periods. Increased nutrients in ground water and sediments are the most likely mechanisms for the correlation between nitrate and land use discussed previously. These two mechanisms, combined with the intermittent poor water quality during storm flows and degraded physical habitats, are contributing factors to the aquatic community changes observed by Mathis in streams draining watersheds with relatively intensive land use.

SECTION THREE - STANDARDS

A number of problems exist with the water quality standards presently applied to the Buffalo River as defined in Regulation No. 2, As Amended; *Regulation Establishing Water Quality Standards For Surface Waters of the State of Arkansas* (ADPCE, 1995). These include:

1.) Specific numeric standards do not exist for several nutrient parameters or sediment.

2.) The Antidegradation Policy of Reg. 2 requires maintenance and protection of existing water quality, especially for those waters designated as Extraordinary Resource Waters. Significant deterioration of present water quality conditions would occur before specific standards are violated.

3.) Standards were developed with point source pollution as the principal cause of degradation. Therefore, they do not account for short duration/high magnitude contributions from storm driven nonpoint source pollution. As discussed previously, storm events produce fecal coliform concentrations which exceed specific standards even from wilderness areas. Rain generated increases are addressed in Reg. 2 as natural phenomenon which, on occassion, exceed the limits applied for this criteria. However, storm events from agriculturally influenced watersheds can produce peak coliform counts which exceed primary contact standards by 112 times and are 90 times higher than peaks from background sites. Present standards fail to address the nonpoint source degradation associated with storm events in any quantitative manner.

The National Park Service would like to propose the development of specific standards for the streams we monitor in the Buffalo River Watershed. Site specific standards would help address items one and two mentioned previously. To facilitate development of specific standards we have prepared Table 1 which gives statistics based on water samples collected during base flow conditions over ten years. We suggest new standards might employ the numbers found in the Average Plus Two Standard Deviations column.

The average and standard deviation numbers were derived by lumping all river samples (top half of Table 1) and tributary samples (bottom half of Table 1) for a referenced parameter. Thus the best sites and worse sites were combined to produce numbers that best reflect the current base-flow conditions for the river or tributaries, as a whole.

Violation of a standard would occur if samples routinely exceeded the reported average plus two standard deviations criteria during base-flow conditions. Currently, none of the river corridor or tributary site averages exceed these values as indicated in the last two columns of Table 1.

Adoption of specific water quality standards for the Buffalo River would be conducted through administrative procedures (Reg. 8) of the Arkansas Department of Pollution Control and Ecology and would require public involvement. While we feel storm discharges from some watersheds exceed allowable levels and are impacting aquatic life and recreational values, we are unclear as to the best way to define standards applicable during periods of nonpoint runoff. Possibly, this issue could be addressed when we work with the state and public to develop specific standards for the Buffalo River.

Table 1: Water quality statistics and proposed standards.

BUFFALO RIVER WATER QUALITY STATISTICS - SAMPLES FROM BASE-FLOW

PARAMETER	Number of Samples	Average	Standard Deviation	Average Plus Two Standard Deviations	Current* Standard	Highest Average	Location
Fecal Coliform Bacteria (col/100 mL)	660	12	28	68	200 - 400	34	R2
Turbidity (NTU)	457	2.2	2.2	6.6	10	2.9	R1
NO3+NO2/N (mg/L-N)	387	0.067	0.096	0.259	None	0.1	R5
Total Kjeldhal Nitrogen (mg/L-N)	216	0.246	0.224	0.694	None	0.32	R1
Orthophosphate (mg/L-P)	283	0.01	0.023	0.056	None	0.025	R9
Total Phosphate (mg/L-P)	278	0.015	0.021	0.057	0.1	0.023	R1
Ammonia (mg/L-N)	297	0.029	0.054	0.137	None	0.046	R9
Chloride (mg/L)	193	2.9	1.422	5.744	20	3.3	R7
Sulfate (mg/L)	275	5.7	2.301	10.302	20	6.6	R9

TRIBUTARY WATER QUALITY STATISTICS - SAMPLES FROM BASE-FLOW

PARAMETER	Number of Samples	Average	Standard Deviation	Average Plus Two Standard Deviations	Current* Standard	Highest Average	Location
Fecal Coliform Bacteria (col/100 mL)	1142	24	49	122	200 - 1000	84	T14
Turbidity (NTU)	873	1.7	2.7	7.1	10	4.5	T1
NO3+NO2/N (mg/L-N)	484	0.15	0.171	0.492	None	0.475	T13
Total Kjeldhal Nitrogen (mg/L-N)	144	0.213	0.166	0.545	None	0.362	T1
Orthophosphate (mg/L-P)	410	0.009	0.025	0.059	None	0.031	T3
Total Phosphate (mg/L-P)	243	0.008	0.016	0.04	0.1	0.019	T10
Ammonia (mg/L-N)	484	0.032	0.048	0.128	None	0.053	T1
Chloride (mg/L)	319	3.2	1.329	5.858	20	4.9	T13
Sulfate (mg/L)	407	7.4	4.942	17.284	20	10	T18&T12

Current FC standard based on geometric mean. Proposed standard uses base-flow conditions with more normal population distribution

Phosphate value is given as a guideline in state standards

SECTION FOUR - RELATED STUDIES AND PROJECTS

National Water-Quality Assessment Program (NAWQA)- USGS

In 1991, the United States Geological Survey (USGS) implemented a nation-wide program to describe the status and trends of surface and ground water resources, and interpret the natural and human factors affecting these resources. The Ozark Plateaus Study Unit was one of the first regions started, and included two basic fixed sites on the Buffalo River. Basic fixed sites are selected for long term water quality monitoring and incorporate monthly sampling, along with limited high-flow sampling, to describe seasonal and temporal fluctuations, estimate loads, and define trends. Parameters analyzed include specific conductance, pH, temperature, dissolved oxygen, and suspended sediments, and chemical constituents that include major ions, nutrients, trace elements, dissolved organic compounds, and fecal indicator bacteria (Femmer and Joseph, 1994).

The two basic fixed sites on the Buffalo River are located at the Upper Buffalo Wilderness Boundary (station R1 in Appendix A) and at Shine Eye, about one mile downstream from the Highway 65 bridge. Benefits of the NAWQA program to Buffalo National River include:

- Verification of sampling efforts and laboratory results performed by BUFF and ADPCE on a routine, river-wide basis.
- Ability to compare water quality findings from the Buffalo River to Ozark streams with more intensive land use activities.
- Analysis of trace elements, pesticides, hydrocarbons, and other anthropogenic organic compounds. These parameters require sophisticated quality control techniques and laboratory analyses, and are therefore too costly for BUFF to perform.
- Completion of a wide range of ecological assessments including algae (periphyton), macroinvertebrate, and fish communities.
- Characterization of instream and riparian habitat.
- Collection of bed sediment and tissue (Asiatic clams or fish) samples for trace elements and hydrophobic organic compounds.
- Independent analysis and publication of a wide spectrum of data collected from the Buffalo River watershed.

In addition to the two basic fixed sites, the Ozark Plateaus NAWQA Program also collected synoptic surface water quality samples from the Little Buffalo River near Murray, Shop Creek near Parthenon, Richland Creek near Witts Spring, Water Creek near Evening Star, Big Creek near Big Flat, and the Buffalo River near Eula. Ground water samples were also collected from one well and from Yardell and Gilbert Springs.

In January of 1994, the National Park Service and the USGS signed a formal Memorandum of Understanding to coordinate and assist in funding the NAWQA Program in parks. In 1996, the NPS Water Resources Division funded continued monitoring at the Buffalo River sites. The Ozark Plateaus NAWQA Program has collected considerable amounts of data and produced several reviews of previously collected data (Bell et. al., 1996; Adamski et. al., 1995; Davis et. al., 1995; and Adamski and Pugh, 1996), published reports concerning organic compounds (Bell et. al., 1997), and have published their data in spread sheet form through the Arkansas District annual data report (Porter et. al., 1996).

Buffalo River Liquid Waste Management System Demonstration Project - Arkansas Department of Pollution Control and Ecology (ADPCE)

In 1992, ADPCE placed a moratorium on the permitting of confined animal operations utilizing liquid waste management systems within the Buffalo River watershed. The major reason for the moratorium was the recognized threat posed by these operations to the water quality of the Buffalo River. At that time, there were 21 permitted liquid waste systems in the Buffalo River watershed; eleven hog farms and ten dairies. Site investigations by ADPCE inspectors revealed 16 operations had numerous problems related to the design and/or management of the waste disposal systems.

In conjunction with the moratorium, ADPCE undertook a comprehensive study of existing liquid waste operations with the intent of determining and correcting ongoing problems, and incorporating design and operation improvements into future permit criteria. Ground water monitoring wells were placed around waste lagoons, and automated sampling stations were installed on drainages leading from the farms. The automated stations collected samples during periods of peak runoff when lagoons had the greatest potential to overflow, and waste application fields are flushed. At this time, no formal results have been released from these studies. The original studies were being conducted at hog facilities, but a recent grant from the Environmental Protection Agency has allowed the project to expand to dairy operations.

Biological Monitoring - University of Central Arkansas

In the late 1980s and early 90s, BUFF initiated a series of comprehensive water resources studies on upper river sites and tributaries (Mott, 1990; Weeks, 1992; Maner and Mott, 1991; Fraser et. al., 1988, Mott, 1991) which elucidated areas of near pristine, and areas of degraded, water quality. Follow-up studies were then conducted to determine if impacts were occurring in the aquatic communities that inhabit the degraded stream reaches. Mathis (1991 and 1992) used community structure and function analyses, richness and diversity indices, and pollution tolerance information to compare sites within the upper watershed. This work showed an apparent correlation between physicochemical water quality findings and associated impacts to stream communities.

Biological methods have distinct advantages over chemical water quality monitoring including:

- The ability to detect the effects of a wide variety of pollutants or anthropogenic alterations of habitat.
- Aquatic communities serve as continuous monitors of sporadic pollutants such as the nonpoint source peaks discussed previously.
- Changes in community structure provide a more direct assessment of the impacts of pollutants

Recognizing these attributes, BUFF, the National Park Service's Water Resources Division, and the University of Central Arkansas are joint sponsors in the development of a biomonitoring program specific to the Buffalo River and its tributaries. The objectives of this project are to:

- Collect community structure data from a variety of near-pristine reference sites to determine the biotic potential of various sized streams in the Ozark physiographic province.
- Collect macroinvertebrate samples from a spectrum of land use intensities using a variety of sampling and community structure analysis routines to determine the least labor intensive method which provides satisfactory correlations between land use, physicochemical results, and biological methods.
- Develop a taxonomic key to aquatic organisms of the Ozark physiographic region.
- Integrate best results/least effort biological monitoring scheme in project W*E*T.
- Use results to develop water quality standards based on preserving biotic integrity rather than maintaining designated uses.

In addition to the macroinvertebrate collections, fish community structures are being sampled and analyzed using the Index of Biotic Integrity as described by Karr (1991). This study represents a major effort requiring five graduate students to complete. Results will be published over the next two years with the implementation of a routine biological monitoring program at BUFF scheduled for 1999.

Land Use Analyses - Arkansas Water Resources Center

Nyquist (1982) studied land use changes in the Buffalo River watershed from 1965 to 1979, and calculated a 43 percent increase in pasture (from 122,175 to 174,525 acres) in only fourteen years. A study limited to a portion of Searcy County reported by Stephenson and Mott (1992) indicated both an increase in the amount of pasture cleared and in the steepness of the slopes being converted to pasture. In other words, as the more desirable level land has already been converted to pasture, new pasture development is occurring on increasingly marginal (i.e. steep) terrain.

In 1994, BUFF contracted with the University of Arkansas to employ a Geographic Information System (GIS) to quantitatively evaluate selected morphological characteristics and temporal changes in the land use of the Buffalo River Watershed. Scott and Hofer (1995) digitized land use characterizations from four previous time periods (1965, 1972, 1974, and 1979) and used thirty meter resolution Landsat Thematic Mapper imagery to classify Land Use/Land Cover for 1992. These attributes were then overlain upon subwatershed, geology, topography, soils, land ownership, and physiographic province data layers to perform land use conversion analyses to answer specific questions.

Major finding of this study include:

- Regression analyses indicate a loss of 3,619 acres of forest per year. The area of pasture is projected to equal the area of forest by about 2050.
- The acreage in pasture increased by 445% (6,362 to 34,681 acres) for slopes greater than 14 degrees from 1965 to 1992.
- Newton and Searcy counties both lost about 40,000 acres of forest land over the 27 years of the study.
- The greatest loss of forest area occurred in the Springfield Plateau physiographic area and along the Highway 65 corridor.

BUFF continues to work with the Center for Advanced Spatial Technology at the University of Arkansas to refine these analyses and improve their accuracy. Land use analyses serve as the foundation from which many of the water quality interpretations and projections are derived. Given the continued loss of forest, and increases in pasture and other developments within the watershed, further water quality declines will occur unless steps are taken to assure that development recognizes the importance of implementing the State's list of Best Management Practices.

Buffalo River Tributaries, Watershed Plan - Natural Resources Conservation Service

In 1990, the Buffalo Conservation District, Crooked Creek Conservation District, and Newton County Conservation District applied to the Secretary of Agriculture for assistance in preparing a plan to address nonpoint source impacts to the Buffalo River under authority of Public Law 83-566. In 1995, the *Buffalo River Tributaries, Watershed Plan* (NRCS, 1995) was approved and allocated $3.1 million toward land treatment, conservation easements, and technical assistance to promote agricultural practices which protect water quality in the Buffalo River watershed .

Specific Best Management Practices include dairy waste management systems, improvement of 33,000 acres of pasture, protecting 34 miles of riparian forest, cross-fencing, streambank stabilization, and re-establishment of 500 acres of forest on steep slopes. Costs of these measures will be shared at a rate of 75 percent federal funds and 25 percent landowner. The NRCS report is very detailed and relied heavily on water quality data and input provided by BUFF to justify project necessity and formulate corrective actions. It is one of the few NRCS watershed improvement projects which has water quality monitoring occurring before, during, and after the project.

Ground Water Hydrology Investigation - BUFF, USGS, and Ozark Underground Laboratory

A previous study conducted by Aley (1989) demonstrated interbasin transfer of ground water from the Crooked Creek basin to the Buffalo River basin in the vicinity of Pindall. Water quality and spring discharge versus surface recharge analyses in the Mill Creek basin near Dogpatch indicated a potential for interbasin transfer in this area as well. Preliminary geologic reconnaissance indicted similar subsurface conditions as documented in the Pindall study, and two dye traces confirmed transfer of ground water from the Crooked Creek basin to the springs near Dogpatch.

With funding from the NPS Water Resources Division, BUFF is currently contracting with the Ozark Underground Laboratory to determine the size and spatial distribution of this area of interbasin transfer. In addition, the USGS is conducting detailed geologic mapping of the area which will be used in conjunction with ongoing karst inventories to determine structural and stratigraphic influences on ground water migration pathways. This comprehensive study will not only determine the true extent of the ground water recharge area for this portion of the Buffalo River, it will allow evaluation of other areas with similar geologic and hydrologic settings which might also be pathways for interbasin transfer.

Geomorphology Investigations - USGS, ADPCE, BUFF

As part of the NPS Global Climate Change Research, studies were conducted to create a comprehensive understanding of fluvial geomorphic changes to landscape disturbance in the Ozark Highlands. This work included three sites on the Buffalo River (Boxley, Blue Hole, and Shine-Eye) and employed stratigraphic, sedimentologic, historic, photogrammetric, climatic, hydraulic, and channel monitoring records to assess effects of historic land disturbance on stream channel function and stability. According to Jacobson (1994), "the data reveal that in the Buffalo River, post-settlement aggradation by gravel is not as evident as in...other rivers. This result may arise from the greater relief and flashier hydrology of the Buffalo River Watershed; these factors may overwhelm the effects of land-use changes." In other words, the Buffalo River, for the most part, has been able to transport its bedload in spite of increased sedimentation from the surrounding watershed. This in turn results in continued high quality stream habitat.

With the controversy surrounding the banning of gravel mining from Extraordinary Resource Waters in Arkansas, new interest has been generated in determining the effects of major alterations of stream channels on river hydraulics. Personnel from the Arkansas Department of Pollution Control and Ecology are using the Rosgen (1994) stream classification system to determine geomorphic attributes (bankfull width, width/depth ratios, cross-sectional area, etc.) for undisturbed sites in the Springfield and Boston Mountains physiographic provinces. These measurements will be used to compare the degree to which past mining activities have altered the natural pattern of stream channels and provide guidelines for restoration work. Successful implementation of the Rosgen classification scheme in the Ozarks would also provide a starting point from which physical monitoring programs could be developed to determine the impacts of past, present, and future land uses on the Buffalo River and its major tributaries.

Riparian Restoration/Streambank Stabilization Project - BUFF, NRPP

In 1994, BUFF received funding from the Natural Resources Preservation Program of the National Park Service to address land use practices and erosion along streambanks of the river and tributaries. The objective of this effort was to restore 100 feet wide forested buffers throughout the length of the river, even in areas of agricultural production. The major hindrance to this project was rapid erosion rates at some sites, which were losing as much as fourteen feet of streambank per year. Thus some form of bank stabilization was required to allow natural, transplanted, and planted vegetation to get established.

After considering several bank stabilization options, BUFF determined that cedar revetments provided the best combination of stability, aesthetics, biodegradability, and habitat enhancement. Given our legislative requirement to "preserve the Buffalo River as a free-flowing stream" (P.L. 92-237), we felt it was inappropriate to constrain the channel permanently with engineered hard structures. Over the last three years, we constructed over one mile of cedar revetments at thirteen sites, erected three miles of fencing to exclude cattle from riparian buffers, and provided cost share assistance on additional two miles of fencing. Reforestation efforts included transplanting local river cane and saplings, and planting 150,000 seedlings of native hardwoods along 5.4 miles of the river.

Arkansas Water Education Team (W*E*T) - BUFF, ADPCE, USFS, AG&F

Educating the public is one of the most important strategies in dealing with nonpoint source pollution. Three schools within the Buffalo River Watershed (Jasper, Marshall, and St. Joe) are currently taking part in the W*E*T program. The sponsors provide computers, water quality meters, and laboratory equipment to allow these schools to collect and analyze physical, chemical, and biological data from a nearby stream. Two days of training are provided to both students and teachers followed by on-site data collection and laboratory analyses using EPA approved techniques. Monitoring stations are located on the Little Buffalo River, Mill Creek, and Bear Creek and samples are collected each month.

RECOMMENDATIONS

Based on the findings of this report and ancillary studies, the following recommendations are extended:

- Because base-flow water quality results show relatively good water quality in most areas of the river and tributaries, routine sampling of the monitoring network shown in Appendix A should be scaled back to seasonal sampling (one sample from each site every third month, or four samples per year).
- Use the additional time and manpower saved by conversion to seasonal sampling to conduct more intensive site specific studies in problem areas, including additional storm-event sampling.
- Incorporate the biological monitoring protocols presently being developed into BUFF's Water Quality Monitoring Program.
- Continue to work with the Arkansas Department of Pollution Control and Ecology, United States Geological Survey, and other state and federal agencies to collect data and monitor the health of the Buffalo River Watershed.
- Work with the State of Arkansas and the public to adopt site-specific water quality standards for the Buffalo River and its tributaries.
- Continue the dye tracing and geologic mapping and interpretation programs to better understand the Buffalo River Watersheds ground water resources.
- Continue to work with the Natural Resources Conservation Service and other agencies and private landowners to encourage implementation of Best Management Practices.
- Work with the State of Arkansas, the NPS Water Resources Division, other agencies, and private groups to develop a Water Resources Management Plan which recognizes and addresses water related issues affecting Buffalo National River.

Numerous issues face the National River, such as a recent proposal to construct a reservoir on Bear Creek, which were beyond the scope of this report to address. It is the intent of the Water Quality Monitoring Program to remain flexible and react to the most pressing issues as they surface, while continually providing long-term water quality data collection. Land use studies show the watershed is continually developing, and water quality studies are critical to understanding how development is impacting the aquatic resources of the Buffalo River which congress mandated the National Park Service to preserve.

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REFERENCES

Adamski, J.C., Petersen, J.C., Freiwald, D.A., and Davis, J.V., 1995, Environmental and hydrologic setting of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma: USGS, Water-Resources Investigations Report 94-4022, 69 pp.

Adamski, J.C., 1987, The effects of agriculture on the quality of ground water in a karstified carbonate terrain, northwest Arkansas: unpublished M.S. thesis, University of Arkansas, Fayetteville, 124 pp.

Adamski, J.C., and Pugh, A.L., 1996, Occurrence of pesticides in ground water of the Ozark Plateaus province: Journal of the American Water Resources Association, v. 32, no. 1, p. 97 -104.

Aley, T., 1989, Delineation and characterization of the recharge area for Mitch Hill Spring, Buffalo National River, Arkansas: Ozark Underground Laboratory, Protem, MO 69 pp.

Arkansas Department of Pollution Control and Ecology, 1995, Regulation no. 2 as amended, regulation establishing water quality standards for surface waters of the state of Arkansas: ADPCE, Little Rock, AR, 73 pp.

Austin, A.Y., and Steele, K.F., 1990, Nitrate concentration of ground water, northern Madison County, Arkansas: Arkansas Water Resources Research Center, misc. publ. no. 74, Fayetteville, 57 pp.

Bell, R.W., Joseph, R.L, and Freiwald, D.A., 1996, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma - Summary of information on pesticides, 1970-90: USGS, Water-Resources Investigations Report 96-4003, 51 pp.

Bell, R.W., Davis, J. V., Femmer, S.R., and Joseph, R.L., 1997, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma--organic compounds in surface water, bed sediment, and biological tissue, 1992-95: USGS, Water-Resources Investigations Report 97-4031, 30 pp.

Bigger, J.W., and Corey, R.B., 1969, Agricultural drainage and eutrophication: in Eutrophication; causes, consequences, correctives: Proc. International Eutrophication Symposium, Madison, Wisconsin, National Academy of Sciences.

Davis, J.V., Petersen, J.C., Adamski, J.C., and Freiwald, D.A., 1995, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma - Analysis of information on nutrients, suspended sediment, and suspended solids: USGS, Water-Resources Investigations Report 95-4042, 112 pp.

Edwards, D.R., and Danial, T.C., 1992, Environmental impacts of on-farm poultry waste disposal: Bioresource Technology, v. 41, p. 9-33.

Femmer, S.R., and Joseph, R.L., 1994, National Water-Quality Assessment Program - Ozark Plateaus surface-water quality study, fact sheet: USGS, FS 94-015, 2 pp.

Fraser, E.W., Jones, D., and Zimmerman, J., 1988, Report on water quality monitoring of two tributaries of the Buffalo National River: Arkansas College, Battesville, AR, 6 pp.

Hynes, H.B.N., 1972, The ecology of running waters: University of Toronto Press, Canada 555 pp.

Jacobson, R.B., and McKenny, R.A., 1994, Annual Report, Land use and climate impact on the geomorphology of Ozark Highlands streams: USGS, Rolla, MO, 14 pp.

Karr, 1991, Biological integrity, a long-neglected aspect of water resources management: Ecological Applications, 1:66-84.

Maner. M.., and Mott, D. N., 1991, Mill Creek survey: Arkansas Department of Pollution Control and Ecology, Little Rock, AR, 37 pp.

Mathis, M. L., 1992, A survey of the Trichoptera of the upper Buffalo River and its tributaries, with annotations on their distributions and pollution tolerances: Department of Biological Sciences, University of Arkansas, Fayetteville, AR, 27 pp. + App.

Mathis, M. L., 1991, Macroinvertebrate community structure at selected sites on the upper Buffalo River: Department of Biological Sciences, University of Arkansas, Fayetteville, AR, 27 pp. + App.

McCalister, W.K., 1990 The effects of land applied animal wastes on ground-water chemistry in northwestern Arkansas: unpublished M.S. thesis, University of Arkansas, Fayetteville, 160 pp.

Mott, D.N., 1990, Effects of cattle pasture runoff on the water chemistry of the Buffalo River, Boxley Valley, Arkansas: Unpublished masters thesis, Arkansas Water Resources Research Center, Fayetteville, AR, 181 pp.

Mott, D.N., 1991, Water Quality Report, 1985 - 1990: Buffalo National River, Harrison, AR, 36 pp. + App.

Nyquist, M.O., 1982, Analysis of data derived from land cover maps for Buffalo National River: National Park Service, Remote Sensing Section, Denver, CO, 9 pp.

Natural Resources Conservation Service, 1995, Buffalo River tributaries, watershed plan -

environmental assessment: USDA, NRCS, Little Rock, AR, 138 pp. + App.

Porter, J.E., Evans, D.A., and Pugh, A.L., 1996, Water resources data, Arkansas, Water Year 1995: USGS, Water Resources Division, Little Rock, AR, 408 pp.

Roberson, J.A., Cassidy, J.J., and Chaudhry, M.H., 1988, Hydraulic Engineering: Houghton Mifflin Co., Boston, MA, p. 79.

Rosgen, D.L., 1994, A classification of natural rivers: Catena, v.22, p. 169 - 199.

Scott, H.D., and Hofer, K. R., 1995, Spatial and temporal analysis of the morphologic and land use characteristics of the Buffalo River Watershed: Arkansas Water Resources Center Publ. no. MSC-170, 48 pp. + figs.

Steel, K.F., McCalister, W.K., and Adamski, J.C., 1990, Nitrate and bacteria contamination of limestone aquifers in poultry/cattle producing areas of northwestern Arkansas, U.S.: Arkansas Water Resources Research Center, Fayetteville, 3 pp.

Stephenson, T., and Mott, D.N., 1992, GIS analysis determines erosion potential at Buffalo National River Basin: USDI, NPS, Park Science, v. 12, no. 4, p. 4 - 5.

Thornton, K.W., and Nix, J.F., 1985, Water quality monitoring program, Buffalo National River, Boxley Valley, Arkansas: Ouachita Baptist University, Arkadelphia, Arkansas, 215 pp.

Weeks, D.P., 1992, The agricultural impact on the Buffalo River in a sedimentary terrain, Boxley Valley, Arkansas: Unpublished masters thesis, Arkansas Water Resources Research Center, Fayetteville, AR, 111 pp.

APPENDIX A

Location of Water Quality Monitoring Program Sampling Sites